Preliminary Considerations for NEAR's Low-Altitude Passes and Landing Operations at 433 Eros

by

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EXTENDED ABSTRACT

NASA's Near Earth Asteroid Rendezvous (NEAR) mission is nearing its final goal of rendezvous and orbit about the asteroid 433 Eros starting in December 1998. The asteroid 433 Eros is an irregularly shaped body measuring about 20 km by 40 km overall. The plan is to establish an orbit of the NEAR spacecraft (S/C) with increasingly lower altitudes as the one year orbit phase progresses. The navigation during this phase relies on a combination of NASA's Deep Space Network (DSN) radio metric tracking, laser ranging (LIDAR) data from the S/C to the surface of Eros, and on board optical imaging of landmarks on Eros (Ref. 1). This paper is concerned with options for mission design and navigation during for the last two months of the orbit phase, where several close passes to within a couple of kilometers of the surface could be incorporated to enhance the science return. These close passes will culminate with a landing on the surface which will mark the end the NEAR mission.

Two feasible approaches exist to effect low altitude flybys of the Eros surface, enabling high-resolution imagery and localized gravitational measurements. This paper will discuss plans for two types of low passes: (1) tight retrograde orbits which have the drawback of high relative velocity with the surface, and (2) targeted low passes to some latitude and longitude which have the possibility of smaller relative velocity with the surface. The development of these techniques in the paper will include the effect of navigation errors which limit the allowable altitude and orbit geometry. These approaches appear to be different, yet they are derived from the same dynamical situation that exists at a body as distended as Eros. As derived in Ref. 2, the S/C will experience changes in its energy during each orbit according to:

$$\Delta C_2 \propto -r_0^2\, C_{22}\, \rho \,/\, q^3 \cos^4(i/2) \sin(2\omega) + \ldots$$

where 'q' is the orbit periapsis normalized by the mean asteroid radius , 'i' the inclination as measured from the asteroid equatorial plane, 'ω' is the sum of the argument of periapsis and the argument of the ascending node, 'ρ' the asteroid mean density and '$r_0^2\ C_{22}$' is the

dimensional gravity coefficient of 2nd degree and order (i.e., the measure of equatorial ellipticity of the body). The proportionality constant is a function of the orbit eccentricity and the parameter $\gamma = \rho\ T^2 / q^3$ where 'T' is the rotation period of the asteroid. The higher order terms are relatively small for the typical NEAR orbits about 433 Eros.

Changes in orbit energy due to one flyby of the body can be substantial, leading to an impact trajectory or reduced orbit period if $\Delta C_2 < 0$ and leading to escape or increased orbit period if $\Delta C_2 > 0$. The simplest close orbit strategy, already used in the design of the orbit phase of the mission, is to fly in a near-equatorial retrograde orbit ($i \approx 180°$) since for this situation the term $\cos^4(i/2) \sin(2\omega)$ and the net change in energy per orbit is negligible. This fact holds down to small periapsis radii, although the higher order terms begin to become important at very low altitudes. Nonetheless, it is possible to design retrograde orbits that come very close to the ends of the asteroid. A drawback to this approach is that the relative speed between the S/C and asteroid end will be very large. Another drawback of this approach is that only the ends of the asteroid are imaged at high resolution, the pole and mid-longitudes only being imaged from a distance of 10 to 15 km.

In the second type of low altitude flyby, it is possible to design flybys of the body that experience no net change in energy, or that experience a net increase in energy (meaning that the apoapsis of orbit is raised to a higher, safer altitude). These techniques will be discussed in the paper, and a robust strategy of orbit control will be presented which minimizes the possibility of collision with the body. The body-relative speeds in these flybys may be controlled through the choice of target latitude and longitude. This will enhance the close-up imaging science of the surface that will be possible during this type low pass.

At the end of the NEAR mission it is desired to place the S/C on the asteroid surface, possibly obtaining additional scientific information in the process. Proposed here is a conservative approach to landing on the surface which should ensure that the S/C remain on the surface (i.e., does not become thrown from the surface following its impact), impact the surface with a minimum value of ΔV, and allow for the opportunity to obtain additional high-resolution images of the asteroid surface. The basic scenario is simple: (1) place the S/C into a polar orbit about the asteroid; (2) at the appropriate time, perform a de-orbit maneuver to send the S/C onto an impact trajectory with the asteroid pole; (3) at a pre-determined time(s) perform slow-down maneuvers to retard the S/C fall rate; (4) design a two-impulse escape maneuver at the end of the sequence to send the S/C back into a safe polar orbit about the asteroid; (5) after the orbit is redetermined, repeat the procedure with the escape sequence designed to be less conservative (i.e., occur closer to the asteroid surface); (6) repeat the process until the S/C impacts with the asteroid surface. The landing itself would be the termination of one of these drop-in passes. Due to the altitude uncertainties (which cannot be directly sensed by the LIDAR due to its inability to operate at ranges less than a couple of km) the S/C will eventually impact the surface, after which it is assumed that all systems will become inoperative and communications will cease.

The issue of impact speed can be addressed, to first order, by a simple analysis of the trajectory. Assuming that a maneuver occurs at an altitude 'h' above the surface of the asteroid pole, the impact speed can be derived to be (from the energy equation):

$$V_{impact} = [(2\ \mu h)/(R(R+h))]^{1/2}$$

where R is the polar radius of the asteroid and μ is its GM value. Figure 1 shows a plot of this relation for different values of asteroid density. Also, in Reference 3 an analysis of the uncertainties for such a drop-in trajectory is given. The result found there, incorporating uncertainties in the asteroid rotation, mass and gravity field, indicates a 3 sigma uncertainty in altitude of approximately 1.2 km. Thus, to ensure a given impact speed, the final maneuver must be performed before this altitude is reached, leading to an impact speed of 3 to 6 m/s, depending on the actual mass of 433 Eros.

Pointing constraints peculiar to the NEAR S/C for solar array pointing, science pointing, and telecommunications and tracking will be addressed in the paper. Preliminary requirements for telecom and tracking during the low passes and landing approaches will be developed.

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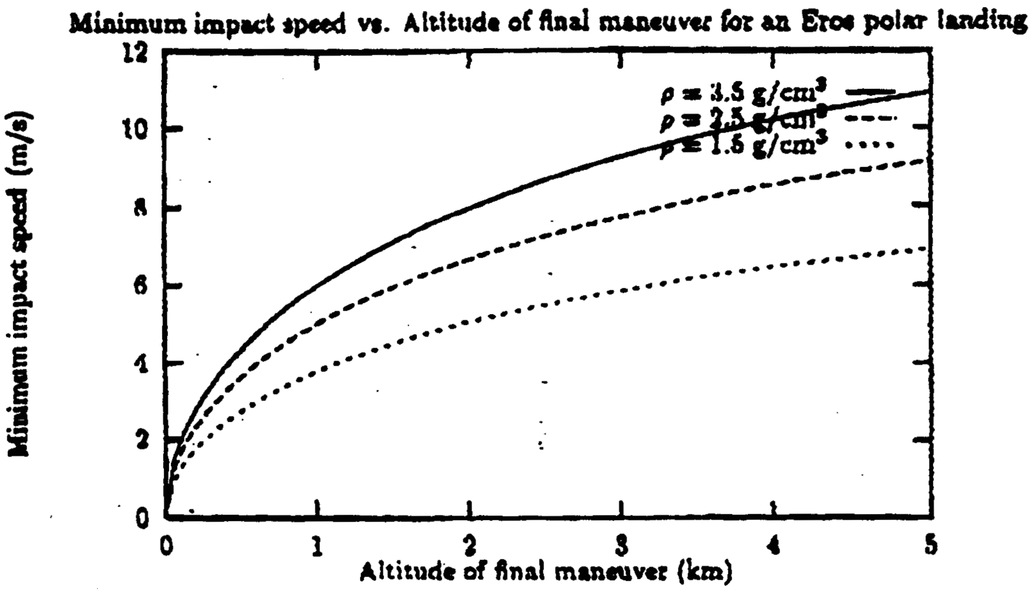

Figure 1. Minimum impact speeds as a function of final maneuver altitude, derived from the 2-body energy integral.